Viability of Hawaiian Forest Tree Seeds in Storage at Various Temperatures and Relative Humidities[1]

Ernest K. Akamine[2]

INTRODUCTION

In Hawaii the Territorial Board of Commissioners of Agriculture and Forestry is charged with the maintenance of forest reserves. Before World War II forest tree seeds were imported from outside sources for reforestation purposes. During the war years, when seeds could not normally be imported because of the critical shipping situation, it was realized that some locally harvested tree seeds could not be kept under ordinary conditions for any extended period without impairment of their viability.

At the request of the Territorial Board of Commissioners of Agriculture and Forestry, studies on the viability of forest tree seeds were pursued at the University of Hawaii Agricultural Experiment Station between the years 1944 and 1948. Seeds of the following trees were tested: paper bark (*Melaleuca Leucadendron* Linn.), brush box (*Tristania conferta* R. Br.), turpentine tree (*Syncarpia laurifolia* Ten.), Norfolk Island pine (*Araucaria excelsa* R. Br.), mamani (*Sophora chrysophylla* Seem.), Monterey cypress (*Cupressus macrocarpa* Hartw.), and Indian sandalwood (*Santalum album* Linn.). It is the purpose of this paper to present the results of experiments designed to develop practical means of prolonging the viability of seeds of these forest trees under storage.

It had previously been found that because the prevailing temperatures and relative humidities of the atmosphere in Hawaii are generally high, seeds of garden, field, and forage crops in ordinary storage deteriorated rapidly (Akamine, 1943). It was further determined that, in order to maintain their longevity, seeds should be stored in a medium in which either the temperature or the relative humidity is kept below that of the atmosphere, or, better still, in a medium in which both the temperature and the relative humidity are kept below those of the air.

Germination and viability studies conducted on forest tree seeds have not been as extensive as those conducted on seeds of other species. Cold storage prolonged the life of Noble fir seed (Isaac, 1934). Moss (1938) found that seeds of three species of *Populus* produced a germination of 70 per cent after a storage period of 2 years under calcium chloride at 23° F. These seeds lost their viability in 2 to 4 weeks when they were stored at room temperature (70° F.). Coniferous seeds have been successfully stored for several years in sealed containers at 36° to 40° F., provided the moisture content of the seeds did not exceed 5 to 8 per cent (Heit and Eliason, 1940; Latour, 1942). The literature on viability studies of forest tree seeds has been reviewed by Toumey and Korstian (1931: 109–152) and by Baldwin (1942: 81–94). More recently Crocker (1948: 28–66) and Porter (1949) also reviewed the work on storage studies of seeds, including those of forest trees.

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[2]Department of Plant Physiology, University of Hawaii College of Agriculture, Agricultural Experiment Station.

EXPERIMENTAL PROCEDURE

The seeds of the seven forest tree species used in these studies were harvested and collected from the various forest reserves throughout the Territory by the foresters of the Territorial Board of Commissioners of Agriculture and Forestry. The viability studies were conducted by the Department of Plant Physiology at the University of Hawaii Agricultural Experiment Station. Freshly harvested and cured seeds were used. Species and their storage periods are listed in Table 1.

Because of the difficulty encountered in most of the species in separating normal embryonated seed from empty seed by external appearance the "per cent normal seed" for each species was determined from internal examination of lots of known numbers of seeds obtained at random (Table 1). Germination tests were conducted on lots of seed counted out at random, and the percentage of germination was based on the "per cent normal seed."

Seeds were stored at relative humidities of approximately 30, 45, 60, 75, and 90 per cent at temperatures of 45°, 59°, and 70°–80° F. (room temperature).[3] The required humidities were maintained with solutions of sulphuric acid of various concentrations (Akamine, 1943) in large desiccators. Some seeds of each species were stored in airtight containers without humidity control at each temperature, and control lots of seeds stored in the open were also included under each temperature. At intervals during the storage period, the specific gravity of the sulphuric acid solutions was determined with a hydrometer, and any divergence from the required specific gravity was corrected by the addition of water or concentrated sulphuric acid.

At the time of storage, an initial germination test was conducted on the seeds of each species. Thereafter, germination tests were conducted at intervals, once in approximately 1 to 2 months, at the beginning of the storage period, and once in approximately 6 months, during the latter part. Data on the germination test period, germination condition, number of replications, and number of seeds per replication for seeds of each species are shown in Table 1. In all cases, tap water was used in the substratum. The sandalwood seed, with its seedcoat removed by hand, was treated with a fungicide ("Thiosan"). The seedcoat was removed to hasten germination, and the fungicide was applied to prevent the contamination of the germination medium by mold organisms. Before testing them, the seeds of mamani were mechanically scarified for 2 to 3 minutes in a shaking machine (Akamine, 1942), using an equal amount of black sand and seed. The black sand was used to abrade the seedcoat, which in this seed is impervious to water and hence requires scarification in order for the seed to germinate. The few hard unswollen seeds remaining at the end of the germination test were nicked on the seedcoat with a knife and left for an additional period to germinate. In all cases, all sound ungerminated seeds left at the end of the test were considered viable and included in calculation of the germination percentage. Because of their enormous size, the seeds of Norfolk Island pine were germinated in a Minnesota seed germinator at room temperature instead of in the petri dish. The criterion of germination was the emergence of normal primary roots and shoots.

EXPERIMENTAL RESULTS

For the sake of brevity, the voluminous germination data on the stored seeds have been omitted in this paper, and, in their place, graphs[4] constructed from these data are presented in Figures 1 to 7. To present the trend of the germination more readily, the curves for these graphs were drawn from points ob-

[3]The cold storage facilities of the United States Department of Agriculture Bureau of Entomology and Plant Quarantine at Honolulu, T. H., were used during the early stages of this study.

[4]The author is indebted to Herbert Sakamoto for the construction of the graphs.

TABLE 1
DATA ON STORED SEEDS OF FOREST TREE SPECIES

COMMON NAME	SCIENTIFIC NAME	STORAGE		NORMAL SEED	GERMINATION TEST			
		STARTED	CONCLUDED		TEST PERIOD	GERMINATION CONDITION*	NO. OF REPLICATIONS	NO. OF SEEDS PER REPLICATION
				per cent	*weeks*			
Paper bark	*Melaleuca Leucadendron* Linn.	May 5, 1944	May 5, 1948	19.1	2	Petri dish	4	200
Brush box	*Tristania conferta* R. Br.	May 5, 1944	May 5, 1948	22.3	2	Petri dish	4	200
Turpentine tree	*Syncarpia laurifolia* Ten.	May 5, 1944	May 5, 1948	42.4	2	Petri dish	4	200
Norfolk Island pine	*Araucaria excelsa* R. Br.	Sept. 26, 1944	Nov. 26, 1945	41.0	3	Germinator	4	50
Mamani	*Sophora chrysophylla* Seem.	Dec. 12, 1944	June 12, 1948	100.0	4	Petri dish	4	25
Monterey cypress	*Cupressus macrocarpa* Hartw.	Jan. 24, 1945	June 24, 1948	6.0	4	Petri dish	4	200
Indian sandalwood	*Santalum album* Linn.	July 18, 1945	June 18, 1948	100.0	3	Petri dish	2	10

*All tests at room temperature (70°–80° F.).

tained by the use of "running averages" of the original data.

Paper bark seed

The germination behavior of this seed in storage at various temperatures and relative humidities is graphically presented in Figure 1. At each storage temperature, the relative humidity has influenced the viability of the stored seed (Fig. 1). In general, the lower the humidity, the longer the seed is kept in a germinative condition. At room temperature, the 45 per cent relative humidity gave results slightly superior to the 30 per cent relative humidity. At 59° F., these two humidities were equally effective in prolonging the life of the seed. The 45 and 60 per cent relative humidities were slightly more effective than the 30 per cent relative humidity for maintaining the viability of the seed in storage at 45° F. At each storage temperature, the seed

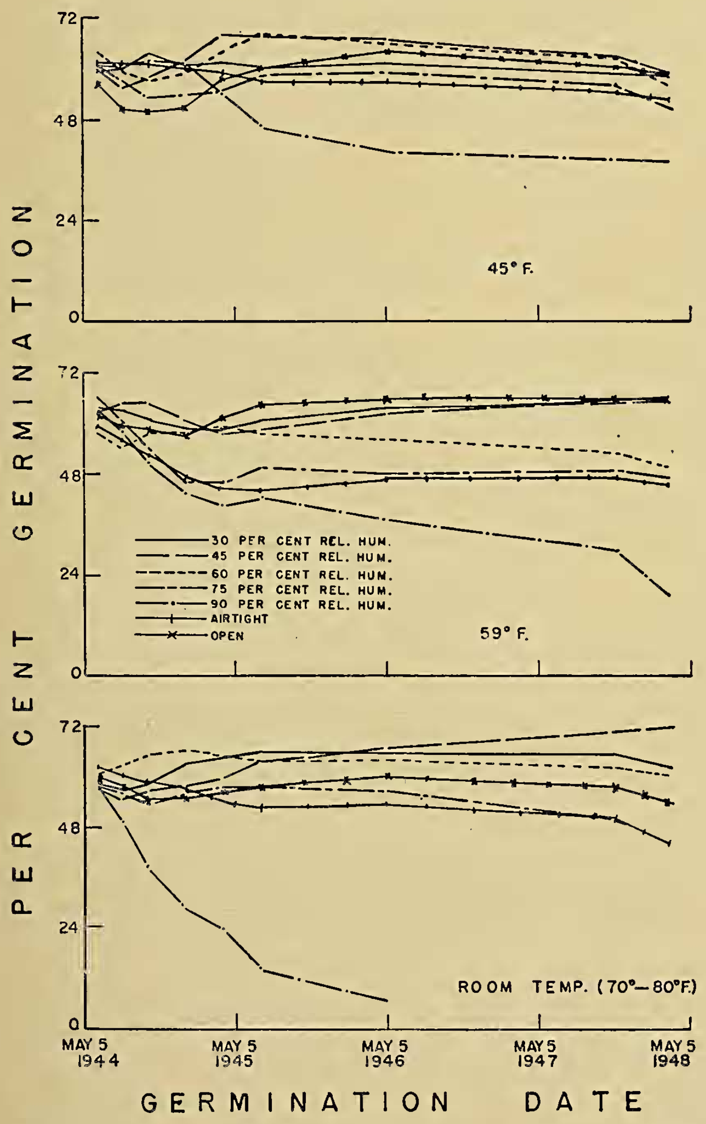

FIG. 1. The effect of temperature and relative humidity on the viability of stored paper bark seed.

kept in an airtight container maintained its viability just as well as that kept at 75 per cent relative humidity. The longevity curve for the seed stored open at room temperature lies approximately midway between the 60 and 75 per cent relative humidity curves. Since the relative humidity of the air is approximately 68 per cent, it seems logical to assume that the curve for the open storage should be in this position. Although no attempt was made to maintain the humidity in the cold chamber and no humidity measurements were made, it may be surmised that seed stored open at 59° F. was subjected to relative humidities in the neighborhood of 30 and 45 per cent because the curves for these storage media lie in about the same plane (Fig. 1). At 45° F., the curve for the open storage lies in the neighborhood of the lower humidity storage curves after the first year of storage.

When the graphs in Figure 1 are superimposed and a critical examination is made of them, it becomes evident that the effectiveness of the two lowest relative humidities (30 and 45 per cent) in preserving the viability of the seed was not influenced by the different storage temperatures. At relative humidities of 60 and 75 per cent and under airtight conditions, 45° F. and room temperature were each equally more effective than 59° F. in preserving the life of the seed. At a relative humidity of 90 per cent, 45° F. was more effective than 59° F., which in turn was more effective than room temperature in maintaining the longevity of the seed. In open storage, 59° F. maintained the viability of the seed more effectively than 45° F. and room temperature, which were equal to each other in effectiveness.

It can be seen from Figure 1 that the viability of the seed of paper bark could be maintained for about 4 years even in open storage at room temperature. The optimum storage condition at room temperature, however, was one in which the relative humidity was kept below that of the air. Generally speaking, at temperatures of 59° and 45° F., open storage was about as effective as the low relative humidities in preserving the life of the seed.

Brush box seed

The germination behavior of the seed of brush box in storage under various conditions is depicted graphically in Figure 2. In general, regardless of the storage temperature, seeds stored at the low relative humidities maintained their viability better than those stored at the high humidities (Fig. 2). At each temperature, the 45 per cent relative humidity was optimum, being superior even to the 30 per cent. The difference between these two humidities in their effectiveness in increasing the longevity of the seed, however, became smaller as the storage temperature was lowered. At room temperature, the germination curve of the seed stored in airtight containers approached that of the seed in the 60 per cent relative humidity storage toward the latter part of the storage period. With prolonged storage at 59° F., the airtight storage curve was near the 30 per cent relative humidity storage curve. At 45° F., the airtight storage was surpassed only by the 45 per cent relative humidity storage in effectiveness in maintaining the viability of the seed. As in the case of the paper bark seed (Fig. 1), the germination curve of the seed stored open at room temperature lies approximately midway between the curves of the 60 per cent and 75 per cent relative humidity storage (Fig. 2). At 59° F., the open storage curve again lies between the 60 and 75 per cent realtive humidity curves, but at the end of the storage period, it had approached the curve of the higher one of these humidities. At 45° F., the open storage curve actually lies below that of the 75 per cent relative humidity curve.

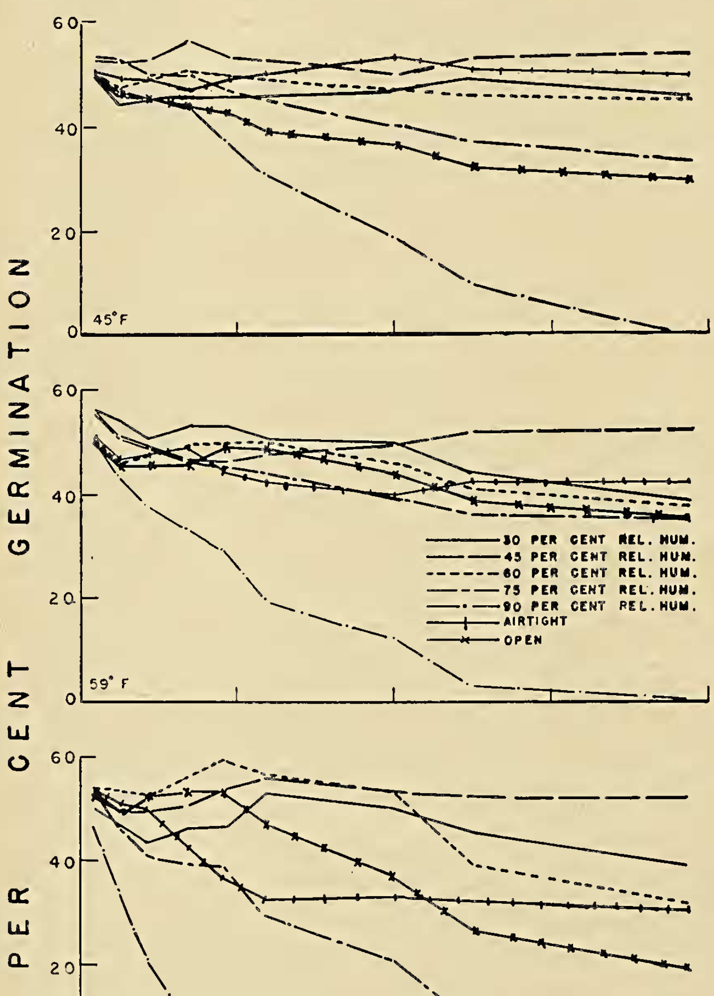

FIG. 2. The effect of temperature and relative humidity on the viability of stored brush box seed.

When the graphs in Figure 2 are superimposed, it is seen that when the seeds were stored at 30 per cent relative humidity, 45° F. was more effective than 59° F. and room temperature in maintaining the viability of the seeds. The two latter temperatures were about equally effective in this respect. The effectiveness of the 45 per cent relative humidity in prolonging the germinative power of the seed was not influenced by the different temperatures employed. At relative humidities of 60 and 90 per cent and in airtight storage, it was found that the lower the storage temperature, the longer the seeds remained viable. Temperatures of 45° and 59° F. were equally more effective than room temperature; in open storage seeds kept at 59° F. remained in a viable state longer than those kept at 45° F. Seeds stored open at the latter temperature in turn kept better than those stored at room temperature.

Since the longevity of the seed at 45 per cent relative humidity was the same at any storage temperature and since this humidity was the optimum for seed storage, it followed that even at room temperature, the seed of brush box could be kept viable for several years provided it was stored at this humidity. Another effective method of prolonging the life of the seed was to store it in airtight containers at 45° F. (Fig. 2).

Turpentine tree seed

The germination results of this seed in storage under various conditions are shown in Figure 3. Seeds stored at different relative humidities behaved differently at different temperatures. In general, at room temperature, the lower the humidity the better the seed kept, although toward the latter part of the storage period, the 45 per cent relative humidity seemed somewhat superior to the 30 per cent humidity. After a prolonged storage period at room temperature, the viability of the seeds in airtight and open storage was approximately the same, and the germination

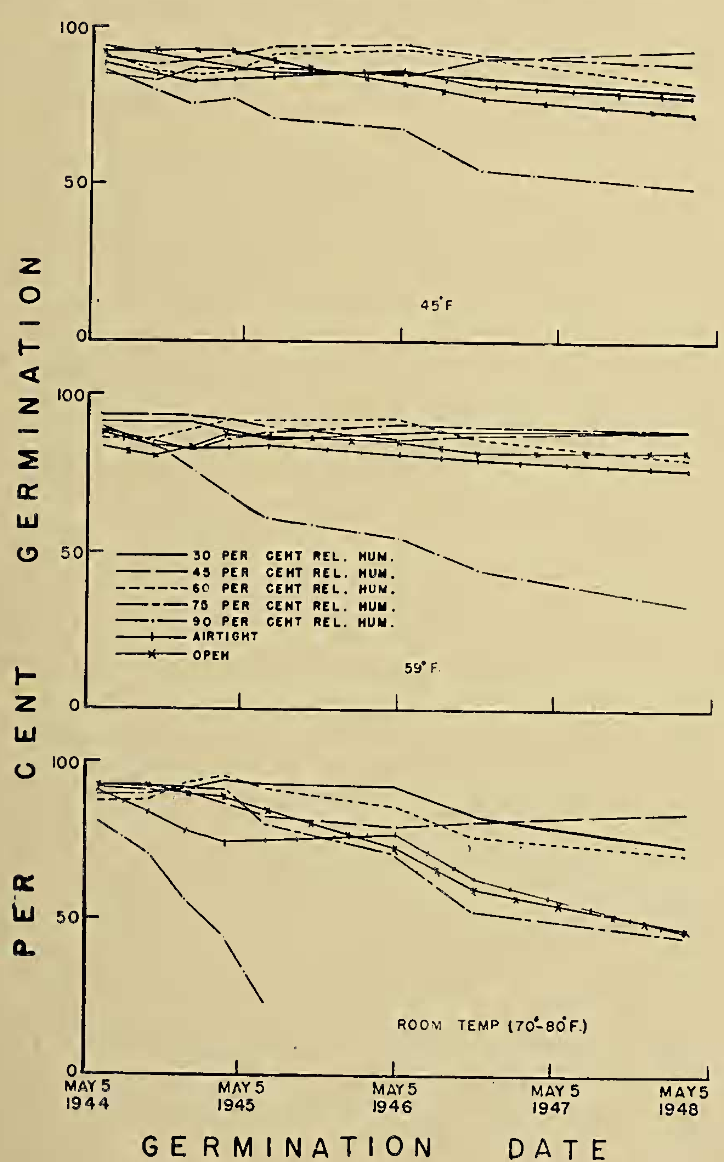

FIG. 3. The effect of temperature and relative humidity on the viability of stored turpentine tree seed.

curves for these seeds lie above the 75 per cent relative humidity curve and below the 60 per cent humidity curve (Fig. 3). Seeds stored at relative humidities of 30, 45, and 75 per cent maintained their original germination after 4 years of storage at 59° F. Storage at a relative humidity of 60 per cent and storage in airtight and open containers were slightly less effective than the above humidities at this temperature. Storage at 90 per cent relative humidity at 59° F. was detrimental to the keeping quality of the seed. With prolonged storage at 45° F., relative humidities of 45 and 75 per cent seemed to be about the optimum media for maintaining the longevity of the seed; relative humidities of 30 and 60 per cent and airtight storage seemed to be the next best storage media. Open storage at this temperature was slightly inferior to the above storage conditions. Storage at 90 per cent relative humidity was inferior to all in retaining the viability of the seed.

When the graphs in Figure 3 are superimposed, it is seen that at a relative humidity of 30 per cent, 59° F. was more effective than 45° F. or room temperature in retaining the viability of the seed. At relative humidities of 45, 60, and 75 per cent and in airtight storage, the seed kept in a viable condition longer at 45° and 59° F. than at room temperature. The two lower temperatures were equally effective in this respect. The loss of viability of the seeds stored at a relative humidity of 90 per cent was proportional to the storage temperature; that is, the higher the temperature, the more rapid was the loss in viability. With open storage, 59° F. was slightly superior to 45° F., which in turn was superior to room temperature in maintaining the life of the seed.

From the above considerations, it seemed that an optimum storage medium for the seed of turpentine tree was one in which the relative humidity was maintained at either 30, 45, or 75 per cent at 59° F., or one in which the relative humidity was maintained at either 45 or 75 per cent at 45° F.

Norfolk Island pine seed

The germination behavior of the seed of Norfolk Island pine in storage at various relative humidities and temperatures is presented in Figure 4. At room temperature, no matter what the storage condition, the longevity of the stored seed was very short (Fig. 4). At this temperature, open storage seemed to be slightly superior to the other types of storage. At 59°F., the lower relative humidities, especially the 45 per cent, preserved the viability of the seed better than the higher humidities. At 45° F., the most striking occurrence was the position of the 30 per cent relative humidity curve. As a storage medium, this humidity was inferior to all the other storage media. The 60 per cent relative humidity at 45° F. seemed about the optimum storage medium, with the 75 per cent humidity a close second. In general, up to a relative humidity of 75 per cent, the higher the humidity, the better the seed kept in a viable state. At a relative humidity of 90 per cent, the seed did not keep any better than that in open storage. Though inferior to the 60 and 75 per cent relative humidities, the airtight storage was superior to the open storage for maintaining the longevity of the seed at 45° F.

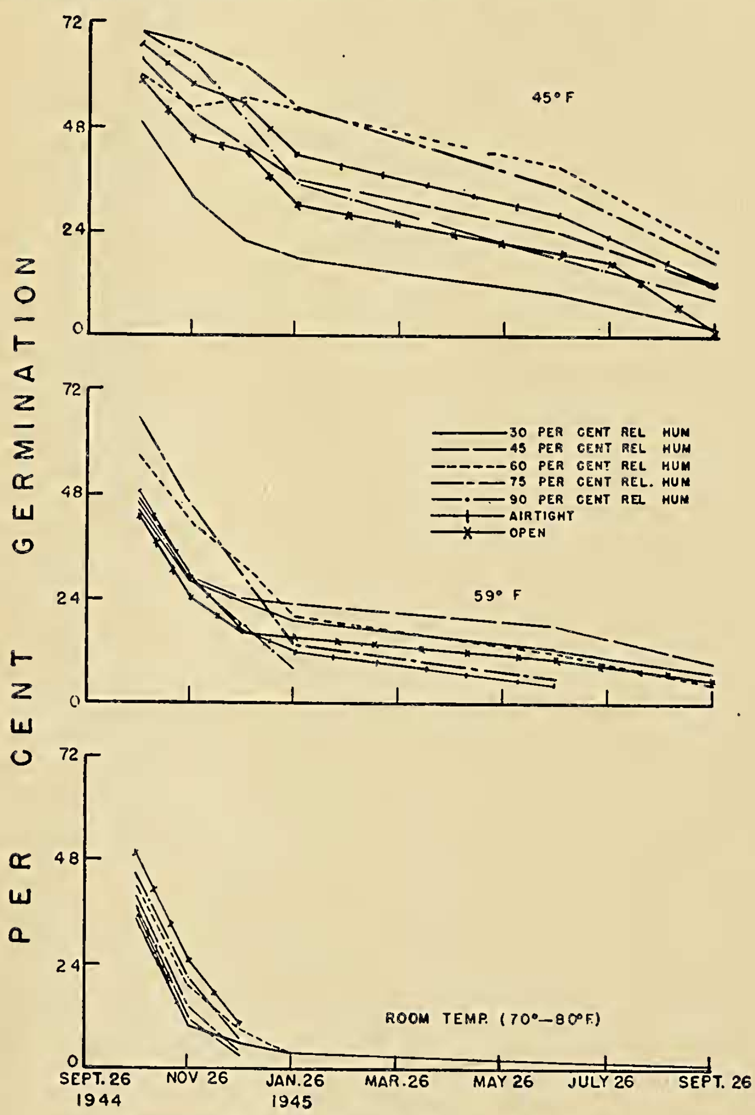

FIG. 4. The effect of temperature and relative humidity on the viability of stored Norfolk Island pine seed.

When the graphs in Figure 4 are superimposed, it will be seen that, in general, the germination curves of the seeds stored at 45° F. lie above those of the seeds stored at 59° F. and that the latter curves in turn lie above those of the seeds stored at room temperature. Thus it seems that regardless of the storage medium, the lower the temperature, the longer was the seed kept in a viable condition.

From the above considerations, it seemed that storing the seed of Norfolk Island pine at a relative humidity of 60 per cent at 45° F. extended the germinative life of this seed.

Mamani seed

In Figure 5 is presented graphically the germination behavior of the seed of mamani in storage under various conditions. Unfortunately, shortage of seed supply necessitated the termination of some germination tests before the experiment was concluded. As a result, in these instances, accurate comparisons between the different storage media could not be made. Nevertheless, it seems that in open storage this seed remained viable for an extended period of time even at room temperature. At the lower temperatures of 45° and 59° F., open storage was probably superior to the other storage media.

When all the storage media are taken into consideration, it seems that as a whole the lower temperatures of 45° and 59° F. were slightly superior to room temperature in maintaining the longevity of mamani seed (Fig. 5). These low temperatures were equally effective in prolonging the viability of this seed.

From the above considerations, it followed

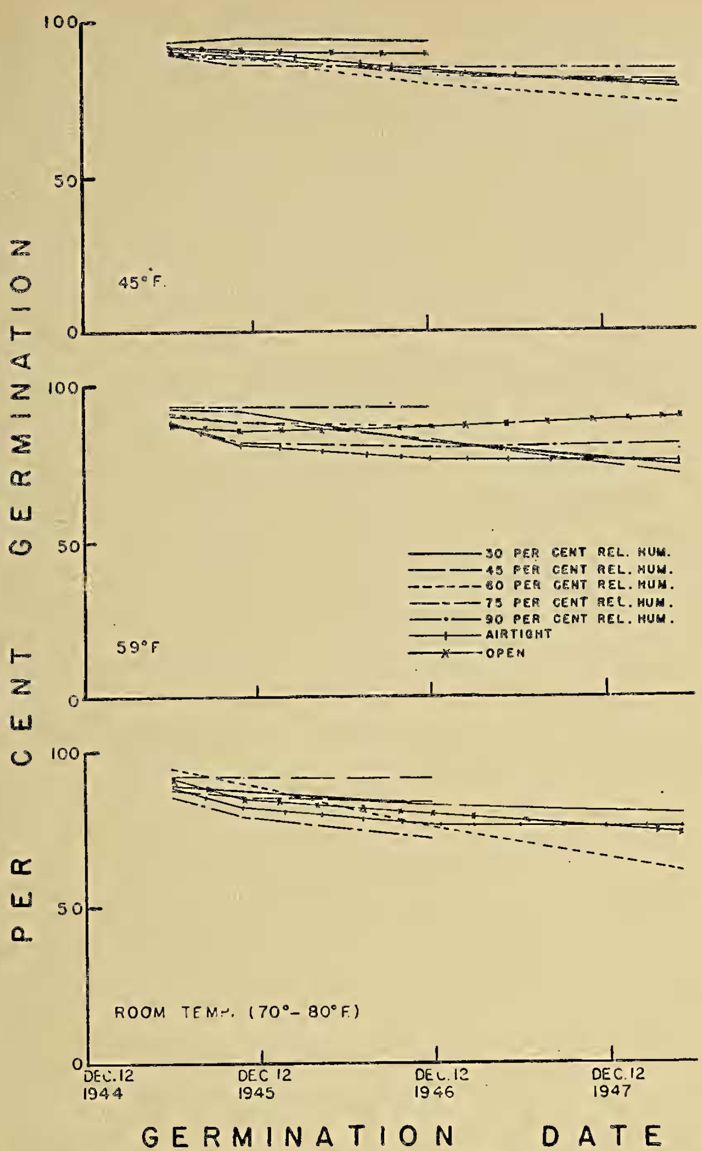

FIG. 5. The effect of temperature and relative humidity on the viability of stored mamani seed.

that storage of mamani seed in the open at temperatures of 59° or 45° F. seemed to be the optimum storage condition for maintaining the viability of this seed over an extended period of time.

Monterey cypress seed

The germination behavior of Monterey cypress seed in storage under various conditions is presented in Figure 6. At room temperature, the lowest and the highest relative humidities were the least effective in maintaining the viability of this seed. The 45 and 75 per cent relative humidities were more effective. The 60 per cent relative humidity was the most effective storage medium at room temperature. The airtight storage and open storage were inferior to only the 60 per cent relative humidity. At 59° F., the 30 per cent relative humidity was the least effective storage medium, and the 60 per cent relative humidity was the most effective. The position of the germination curves of the 45, 75, and 90 per cent relative humidities was approximately midway between the curves of these two humidities (Fig. 6). The curve of the airtight storage approached that of the 30 per cent relative humidity, and the curve of the open storage approached that of the 60 per cent relative humidity. At 45° F., the most effective medium was the open storage, and the least effective was the airtight storage. The 30, 45, and 60 per cent relative humidities were equally less effective than the open storage. The highest relative humidities, 75 and 90 per cent, were somewhat superior to the airtight storage toward the latter part of the storage period in maintaining the viability of the seed at 45° F.

When the graphs in Figure 6 are superimposed, it appears that at relative humidities of

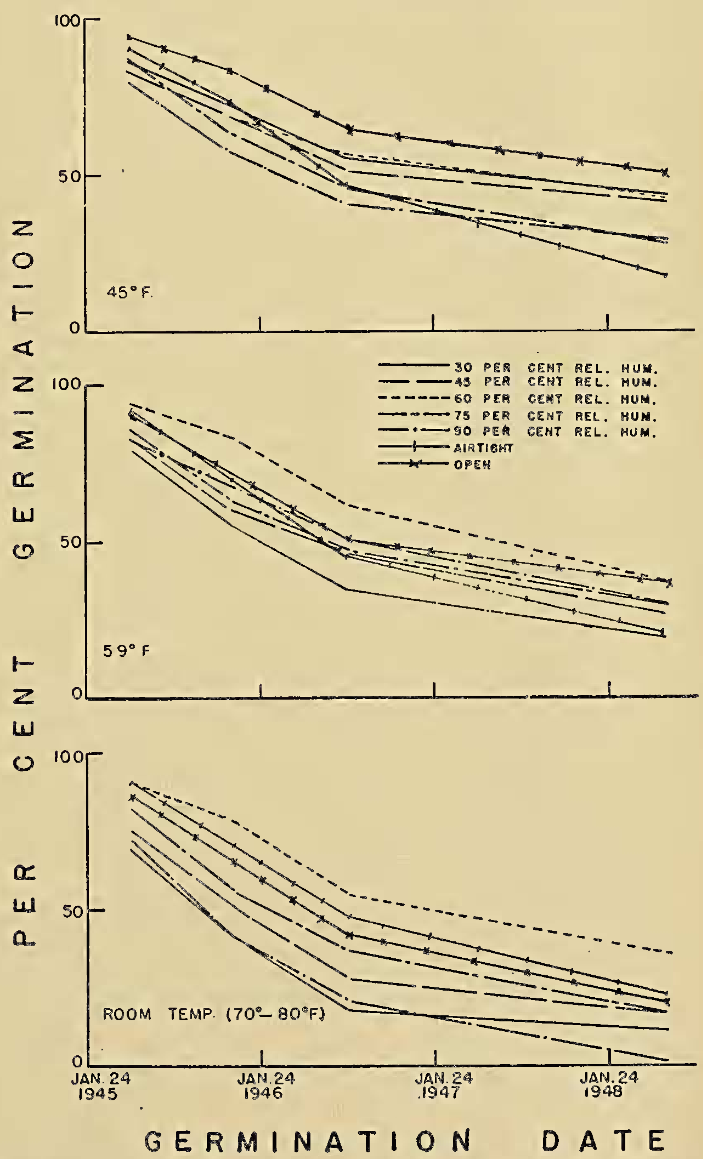

FIG. 6. The effect of temperature and relative humidity on the viability of stored Monterey cypress seed.

30 and 45 per cent and in open storage, the lower the temperature the longer the seed remains viable. At a relative humidity of 60 per cent and with airtight storage, the three storage temperatures were equally effective in preserving the viability of the seed. At 75 per cent relative humidity, temperatures of 45° and 59° F. were equally more effective than room temperature. At 90 per cent relative humidity, 59° F. was more effective than 45° F., which in turn was more effective than room temperature.

From the above considerations, it seemed that storing the seed of Monterey cypress in the open at 45° F. prolonged the life span of this seed better than storing under any other condition.

Indian sandalwood seed

Because of the limited supply of Indian sandalwood seed, only a few seeds were used in the germination tests (Table 1). Nevertheless, the results obtained seemed reliable.

The germination status of this seed at various periods of storage under varying conditions is depicted graphically in Figure 7, which indicates that at room temperature, the low relative humidities of 30, 45, and 60 per cent seemed to be the optimum storage media. The high relative humidities of 75 and 90 per cent were the least effective in preserving the life of the seed. The airtight storage and open storage were intermediate between these humidity groups in this respect. At 59° F., the lower the relative humidity the longer the seed kept viable. The airtight storage and open storage were less effective than the 45 per cent relative humidity but more effective than the 60 per cent humidity at this temperature. In general, the lower relative humidities were more effective than the higher humidities in maintaining the viability of the seed at 45° F. The optimum relative humidity was probably 45 per cent. Seeds stored in airtight containers and in the open retained their viability approximately to the

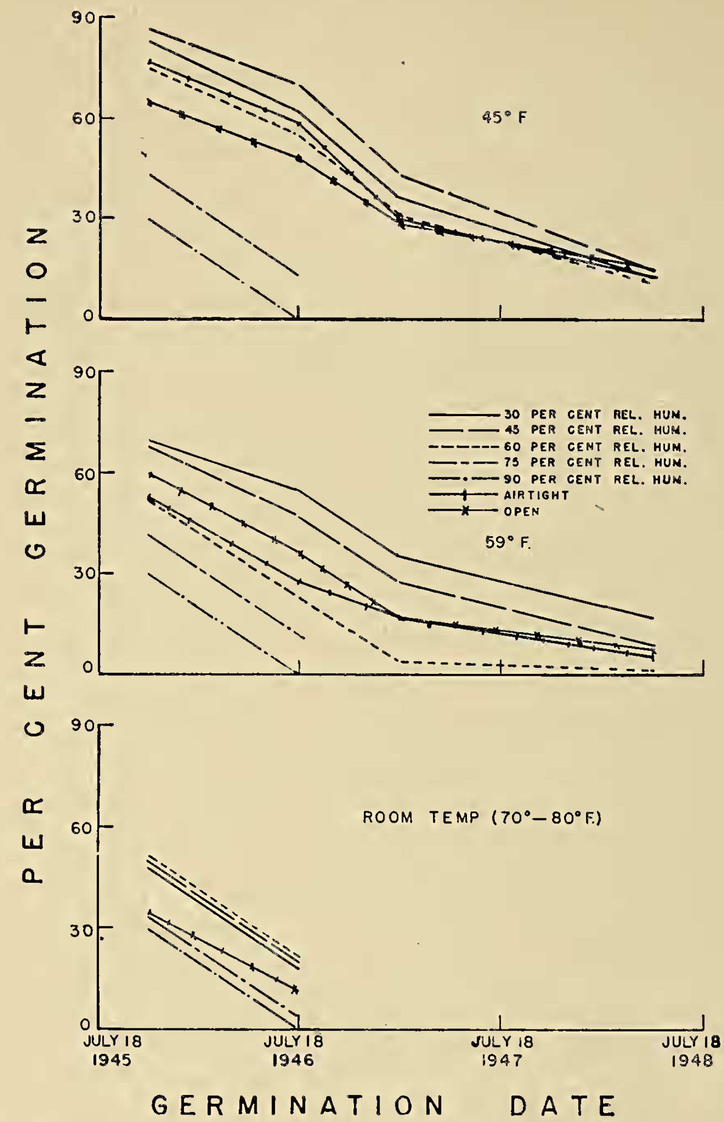

FIG. 7. The effect of temperature and relative humidity on the viability of stored Indian sandalwood seed.

same degree as those stored at the relative humidity of 60 per cent at this temperature.

When the germination curves of the seeds stored at the same humidities at each temperature are compared with each other, it will be seen that at relative humidities of 30, 45, and 60 per cent, 45° F. was more effective than 59° F., which in turn was more effective than room temperature in maintaining the viability of the seed (Fig. 7). At a relative humidity of 75 per cent, 45° and 59° F. were equally more effective than room temperature. At a relative humidity of 90 per cent, the three temperatures were equal in effectiveness. In airtight storage and in open storage, the lower the temperature the longer the seed remained viable.

From the above considerations, it can be stated that the optimum storage condition for Indian sandalwood seed was one in which the temperature and the relative humidity were maintained at 45° F. and 45 per cent, respectively.

DISCUSSION

If the longevity of the seeds of all species under all conditions of storage is considered as a whole, it will be seen that these seeds fall in one of the following groups: long-lived seed, medium-lived seed, and short-lived seed. The seed of mamani falls in the first group. In the second category fall the seeds of paper bark, turpentine tree, and brush box. The seeds of Monterey cypress, Indian sandalwood, and Norfolk Island pine are short-lived.

The retention of viability by the seed of mamani was probably due to the impervious nature of its seedcoat, which interfered with the uptake of moisture and with respiration. It will be remembered that this seed required scarification for germination. Generally speaking, regardless of the condition of storage, this seed maintained its viability for 3½ years (Fig. 5).

In general, among the medium-lived seeds, the seeds of paper bark and turpentine tree maintained their viability in storage for 4 years, slightly better than the seed of brush box (Figs. 1, 2, and 3).

In general, among the short-lived seeds, the seed of Monterey cypress retained its viability better than that of Indian sandalwood, which in turn maintained its viability better than the seed of Norfolk Island pine (Figs. 4, 6, and 7).

Although different species reacted somewhat differently toward the various storage conditions, in general, the lower relative humidities were more conducive than the higher humidities to the preservation of viability. There were, however, two species (Monterey cypress and Norfolk Island pine) which were exceptions to this statement. Monterey cypress seed stored at 30 per cent relative humidity at room temperature did not maintain its viability any better than that stored at 90 per cent relative humidity at this temperature (Fig. 6). The 30 per cent relative humidity at 59° F. was the least effective storage medium for this seed. At a temperature of 45° F., the 30 per cent relative humidity was also the least effective storage medium for the seed of Norfolk Island pine (Fig. 4).

SUMMARY

The effects of temperature and relative humidity on longevity of seeds of seven forest tree species in storage for several years were studied.

Although seeds of different species reacted somewhat differently toward the various storage conditions, in general it can be stated that the longevity of these seeds can be maintained in Hawaii if the temperature of the storage medium is maintained at a lower level than that of the prevailing atmosphere (70°–80° F.), if the relative humidity is maintained at a lower level than that of the prevailing atmosphere (66–71 per cent), or if both the temperature and relative humidity are maintained at lower levels than those of the air.

The following were found to be the optimum media for the storage of seeds of the individual species in Hawaii:

- Paper bark—Relative humidity of 45 per cent at room temperature or open storage at 59° F.
- Brush box—Relative humidity of 45 per cent at room temperature or airtight storage at 45° F.
- Turpentine tree—Relative humidity of 45 per cent at 59° F.
- Norfolk Island pine—Relative humidity of 60 per cent at 45° F.
- Mamani—Open storage at 59° F.
- Monterey cypress—Open storage at 45° F.
- Indian sandalwood—Relative humidity of 45 per cent at 45° F.

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